

Fabrication and Testing of Advanced Thermoelectric Unicouples for Power Generation

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by

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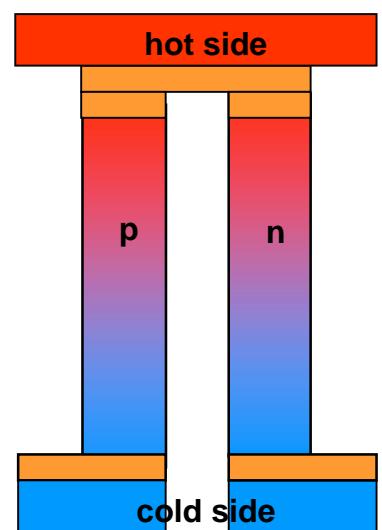
Jet Propulsion Laboratory/California Institute of Technology

Pasadena, CA, USA

Program overview

- Engineering and testing
- Unicouple fabrication
- Modeling

- Materials Research
- Develop high ZT materials
- Materials synthesis
- Improve thermal stability and compatibility

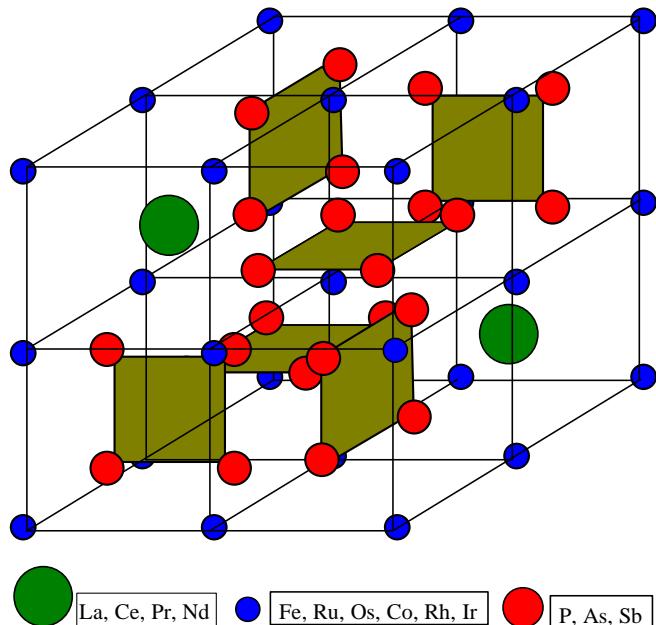


- High-efficiency prototype

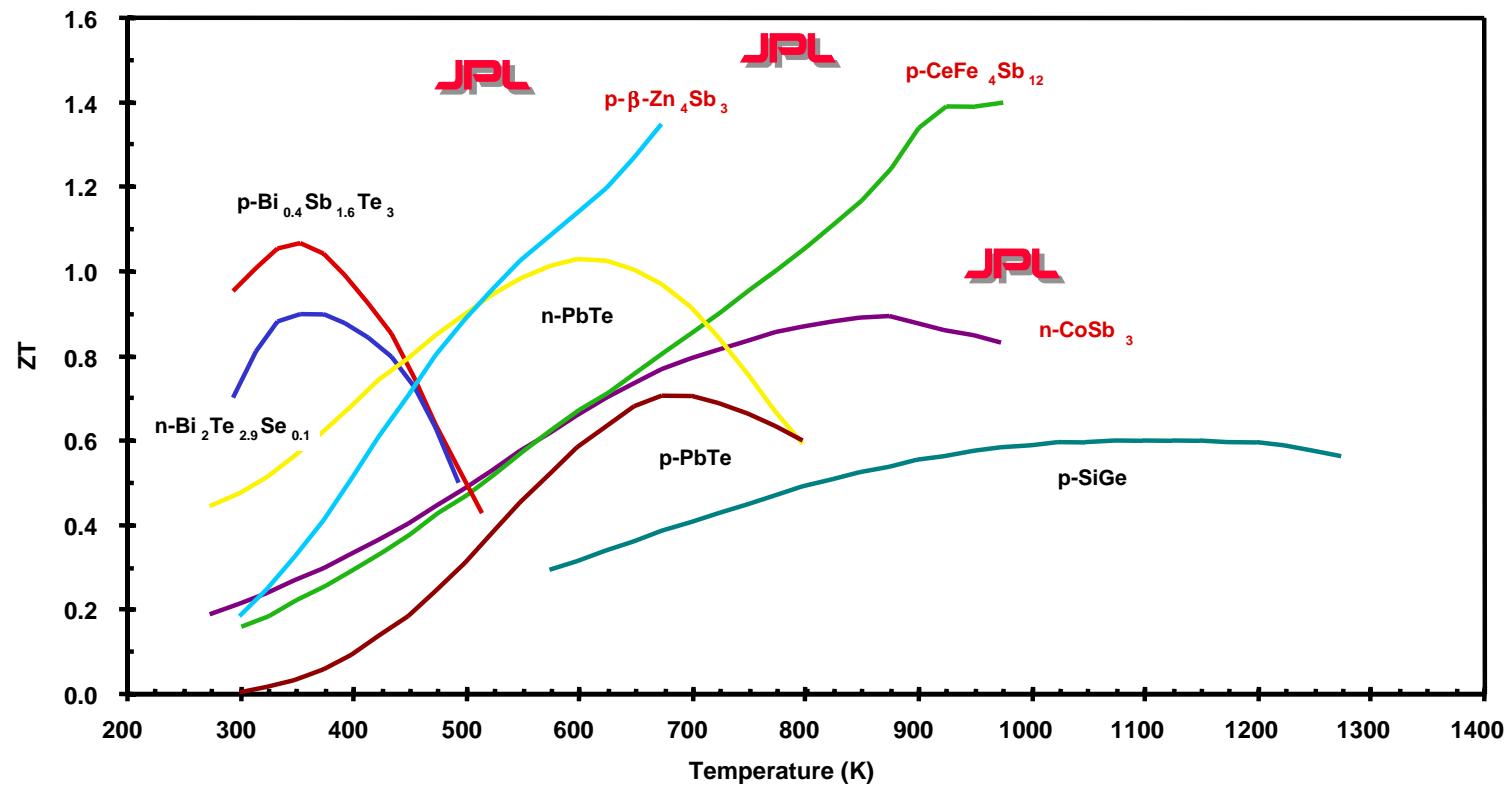
Advanced Thermoelectrics DARPA & ONR effort at JPL

■ Bulk materials

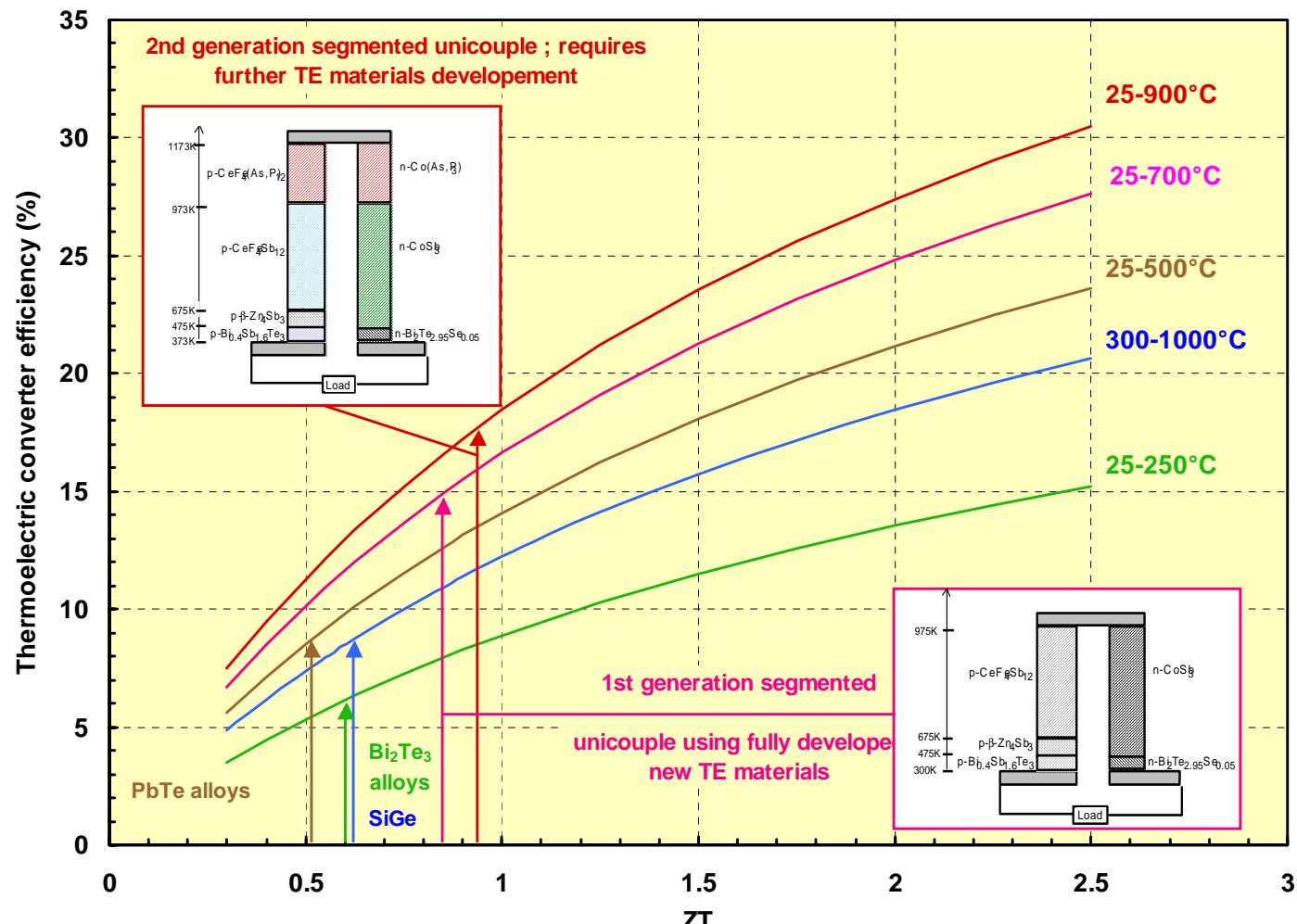
- DARPA “Advanced Thermoelectrics” and ONR “Skutterudites”
 - ◆ Focus on TE materials for cooling and power generation up to 600-700°C
 - ◆ Identification, characterization and optimization of some new, promising materials
 - ◆ Skutterudites



Best ZT to date on new materials developed at JPL



- Combine best new material (Skutterudite) with the best SOA (BiTe)



- Projected performance is double SOA technology

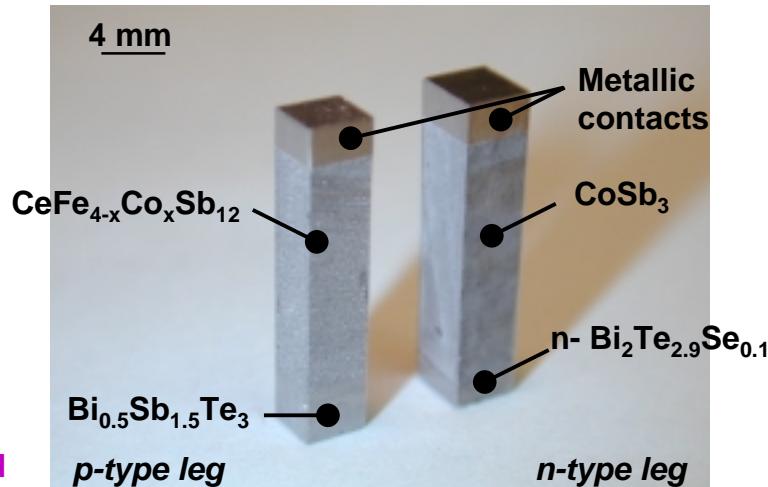
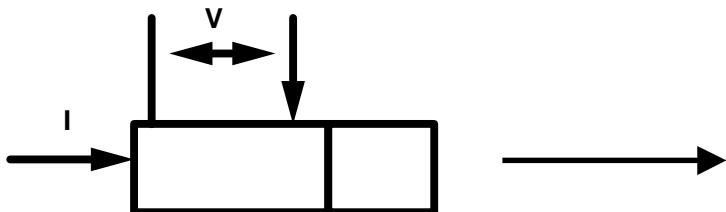
Segmented legs: fabrication and testing

■ Segmented leg fabrication

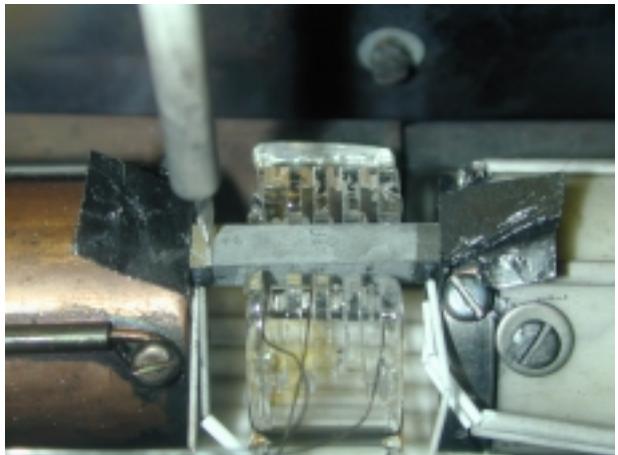
- Uniaxial hot-pressing of powder stacked on top of each other
 - ◆ Temperature optimized → density close to theoretical value
 - ◆ In graphite dies and argon atmosphere
- With metallic foil between segments
 - ◆ Selected to compensate for coefficient of thermal expansion mismatch
 - ◆ Diffusion barrier
 - ◆ Should react chemically with both materials to be bonded
 - ◆ Low electrical resistance bond ($<10\mu\Omega\text{cm}^2$)
- Metallic contacts at hot-side

■ Bond quality

- Electrical contact resistance measurement
- Microprobe analysis
 - ◆ Diffusion
 - ◆ Chemical reaction and interface layer analysis

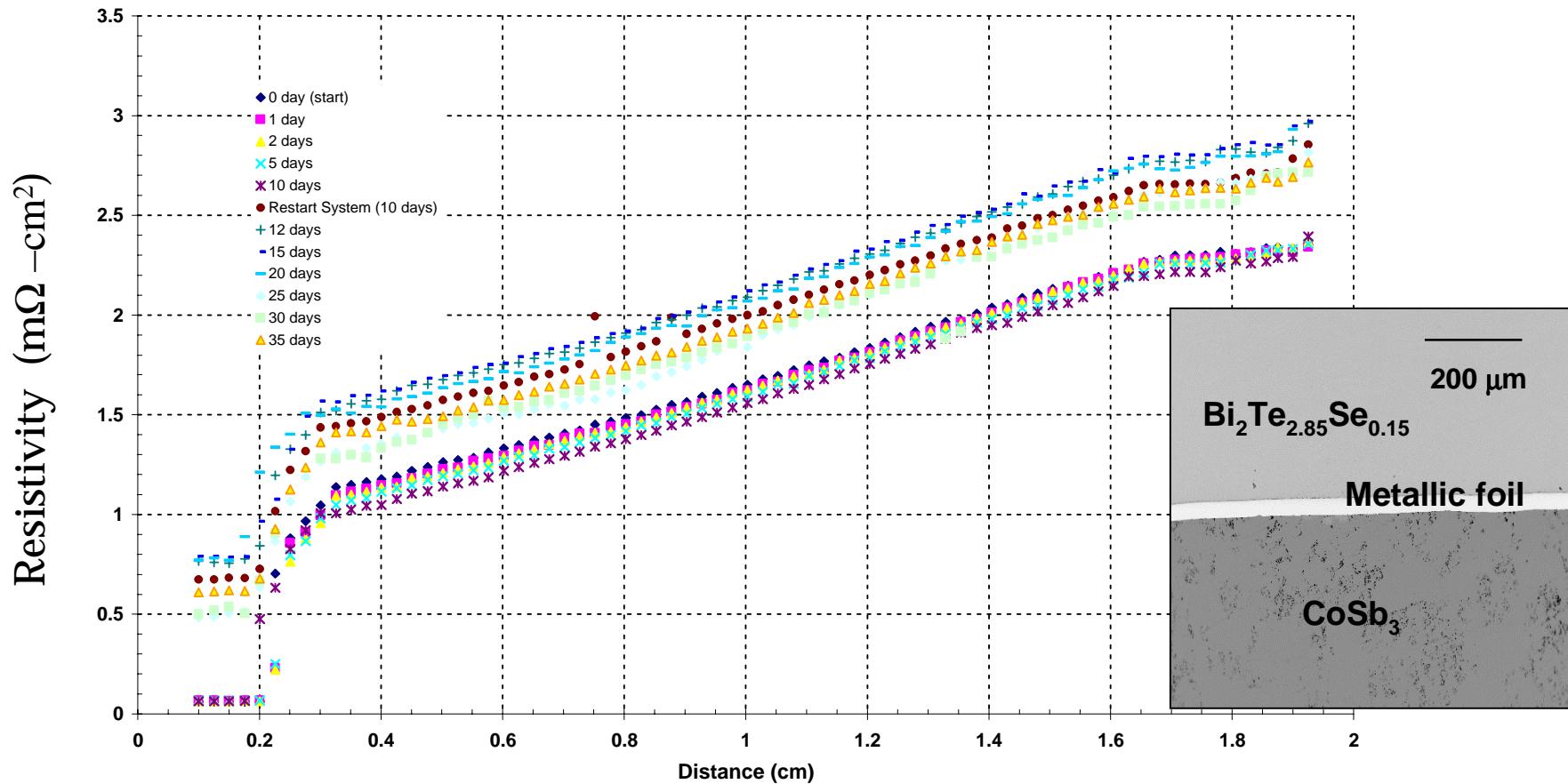


Segmented legs fabricated by uniaxial hot-pressing



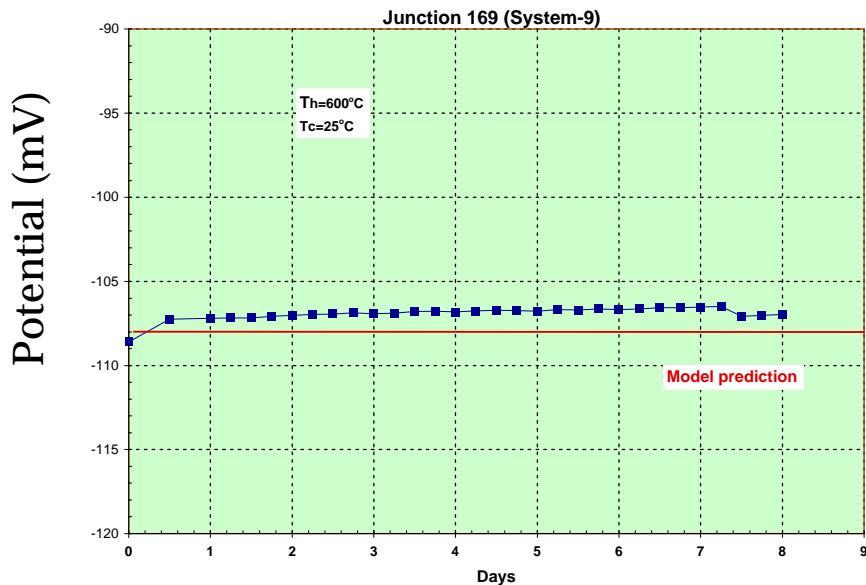
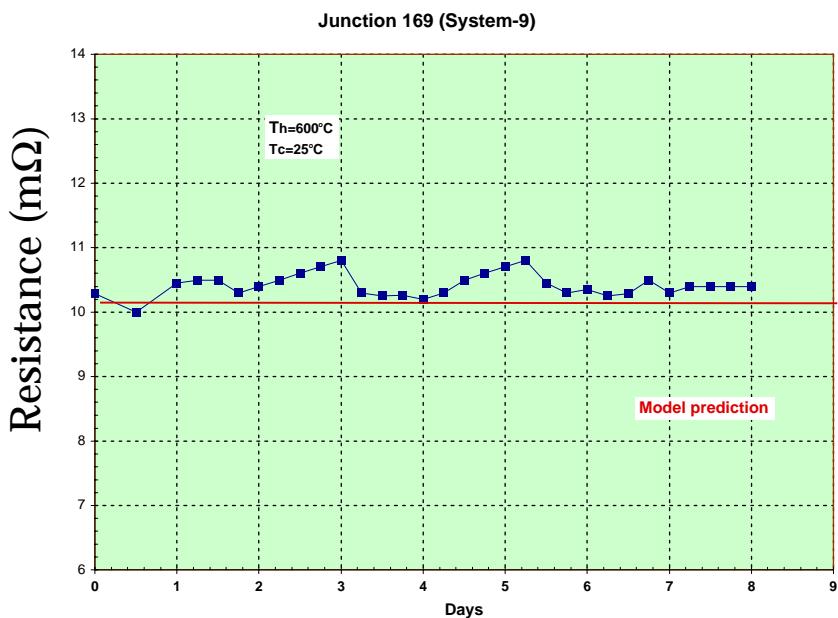
*In gradient, electrical contact resistance life tests on
 $\text{Bi}_2\text{Te}_{2.85}\text{Se}_{0.15}/\text{CoSb}_3$ segmented leg (n-type)*

Junction-169 (Resistivity at 600°C vs Time)

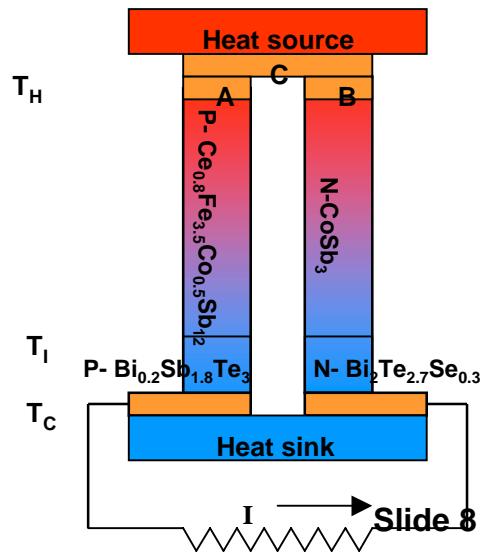


- Demonstrated low electrical resistance contacts between $\text{Bi}_2\text{Te}_{2.85}\text{Se}_{0.15}$ and CoSb_3 segments

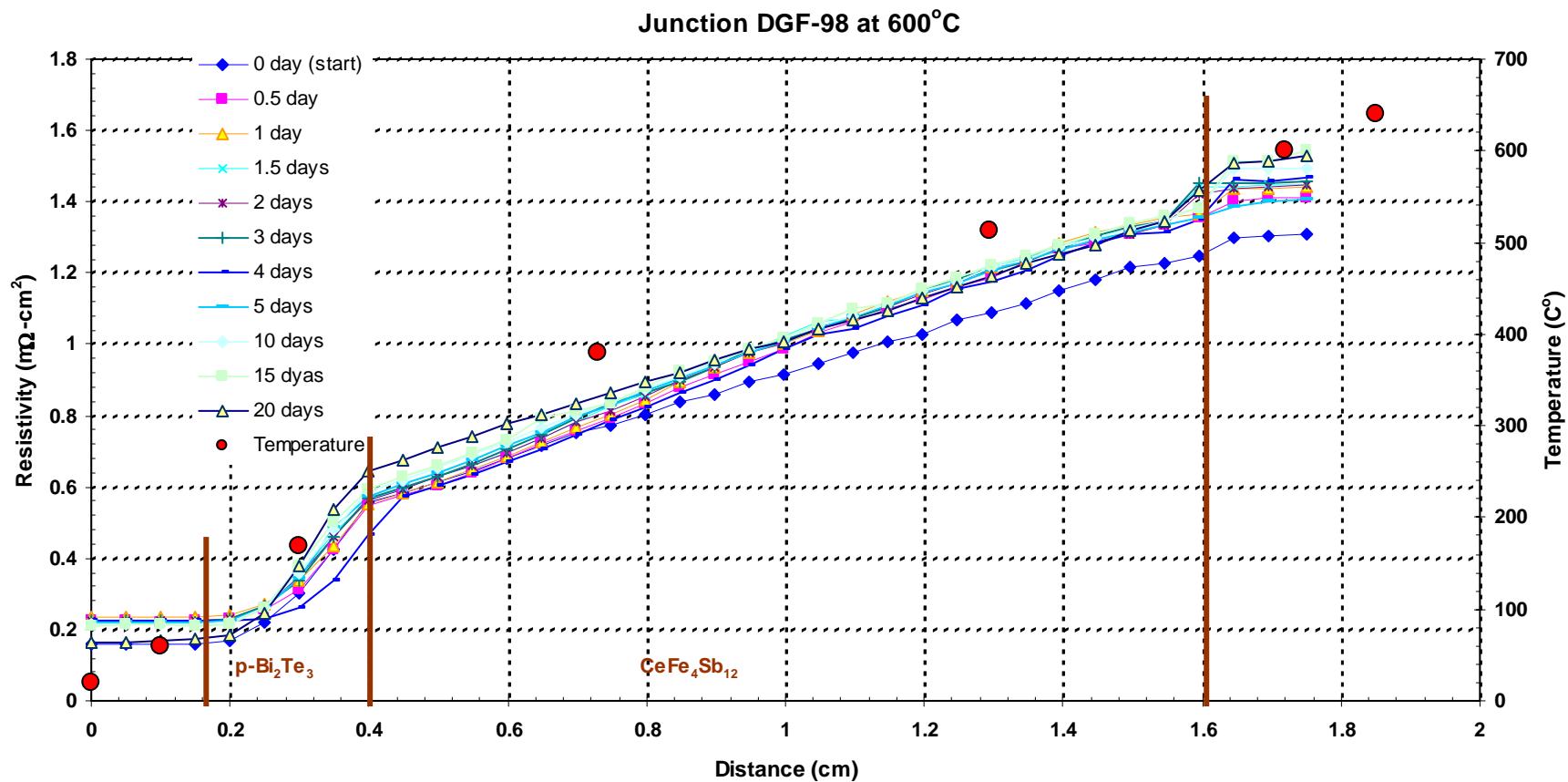
In gradient voltage output and resistance measurements for $\text{Bi}_2\text{Te}_{2.85}\text{Se}_{0.15}$ / CoSb_3 segmented leg (n-type)



- Results validate thermoelectric properties of n-type CoSb_3 , $\text{Bi}_2\text{Te}_{2.85}\text{Se}_{0.15}$ / CoSb_3 segmented leg
- Confirms low electrical contact resistance between segments



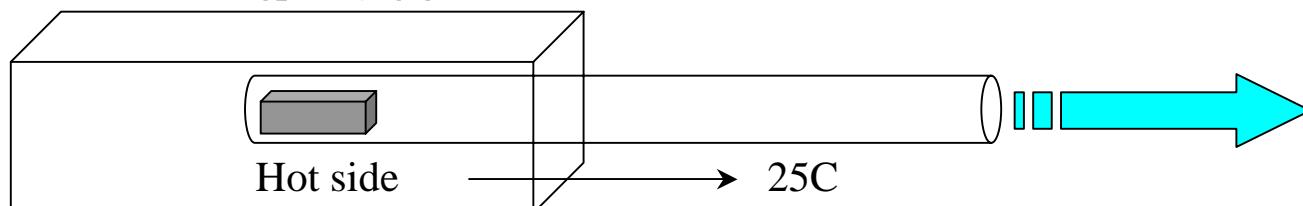
*In gradient electrical contact resistance life tests on
 $Bi_{0.4}Sb_{1.6}Te_3/CeFe_4Sb_{12}$ segmented leg (p-type)*



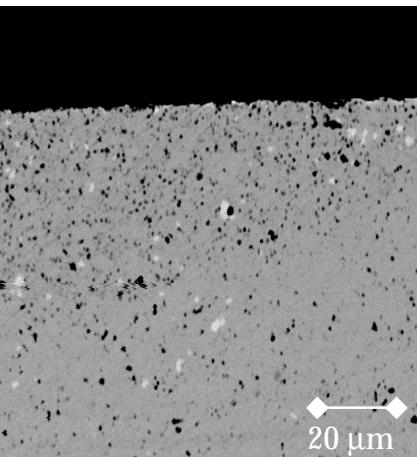
- Demonstrated low electrical resistance contacts between $Bi_{0.4}Sb_{1.6}Te_3$ and $CeFe_4\text{Sb}_{12}$ segments

n-type temperature stability

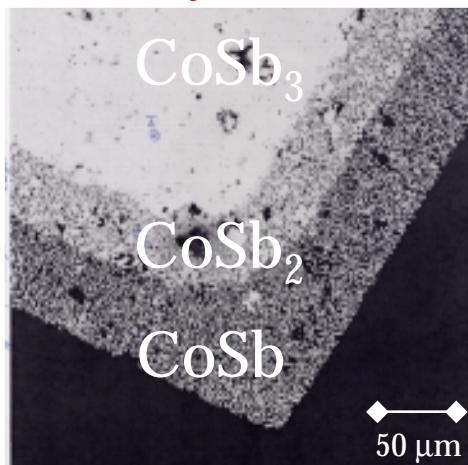
Furnace



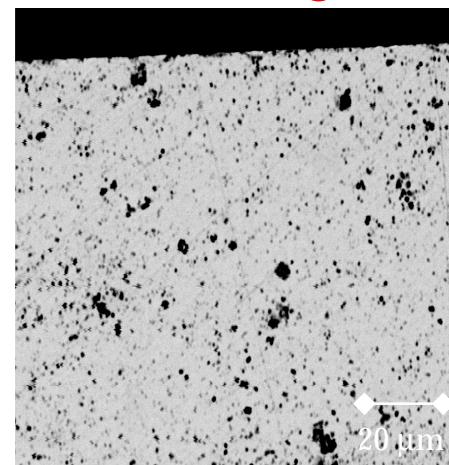
As-pressed



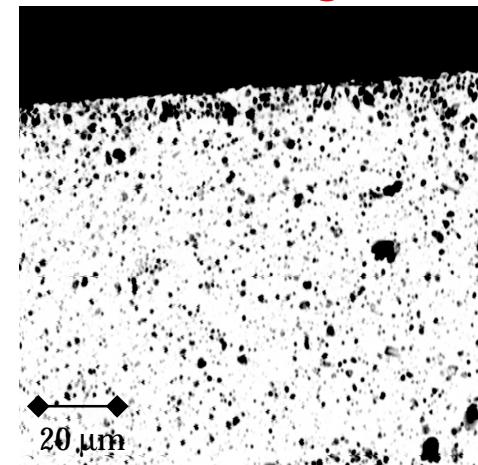
600 dynamic



600 cover gas

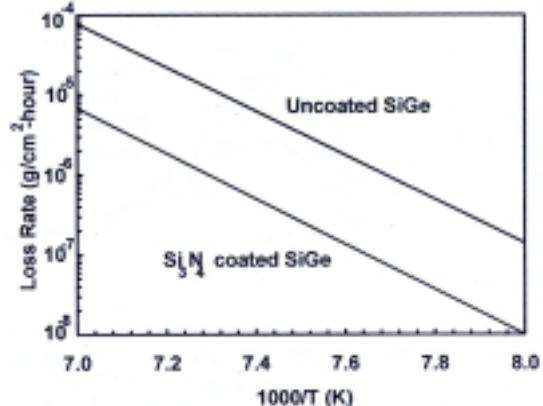
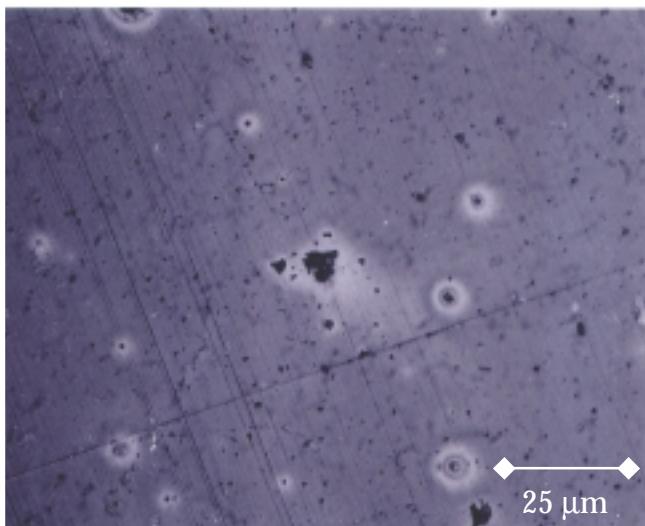
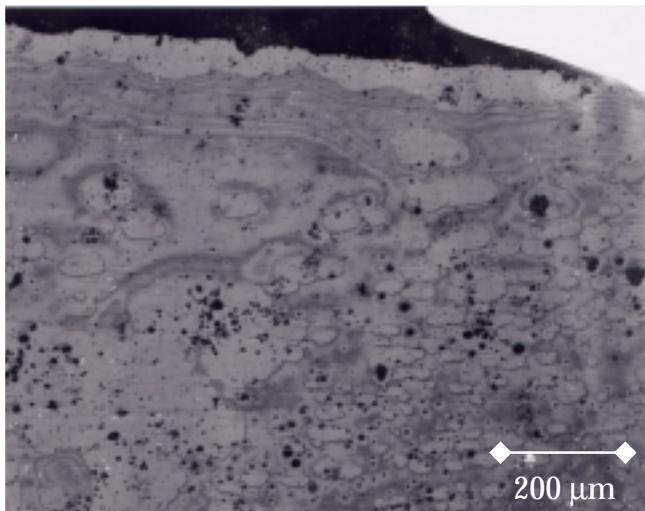


700 cover gas



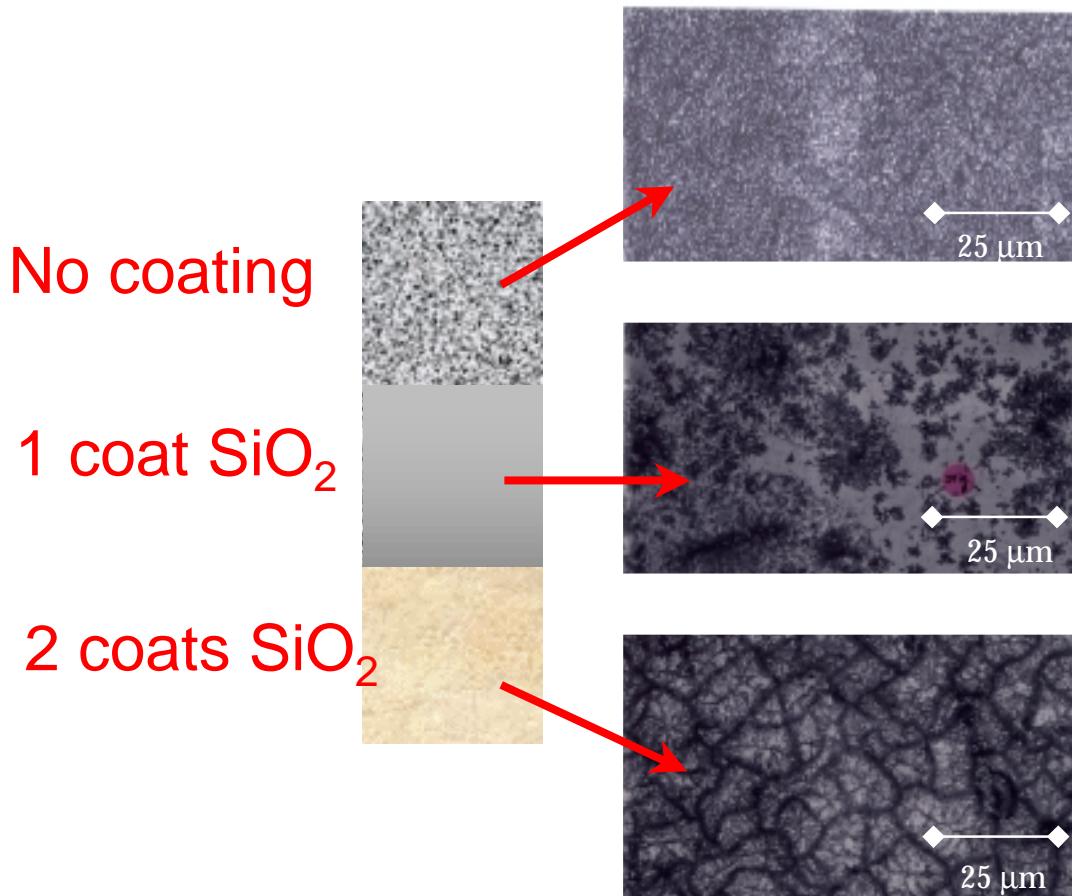
- Temperature stability tests have identified Sb sublimation as the predominant material dissociation mechanism in dynamic vacuum
- Cover gas suppresses Sb sublimation

Sol-gel silica coatings



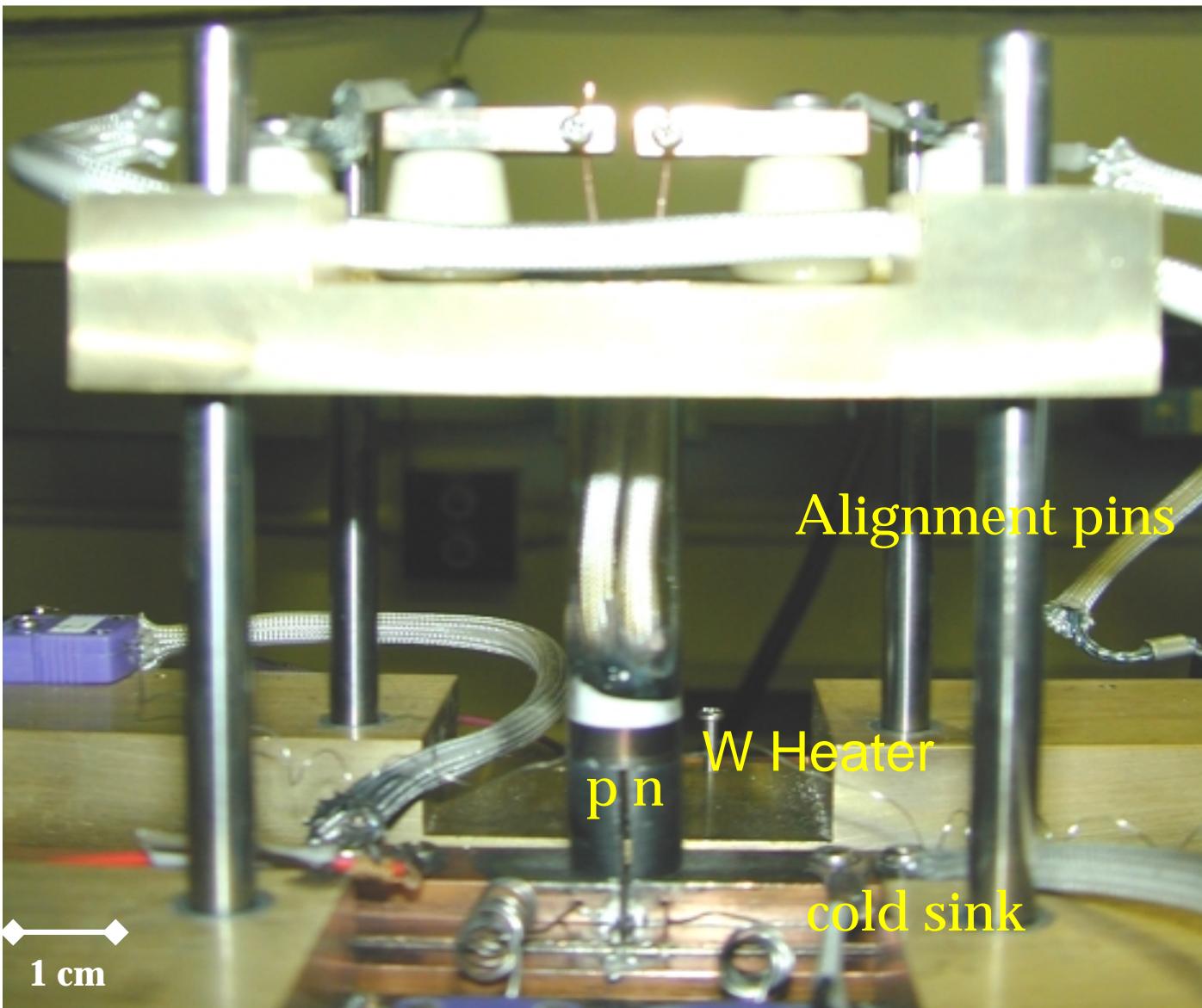
- To prevent sublimation in vacuum; use coating similar to SiGe technology
- Sol-gel; dip coating SiO₂ method
- 1 coat: <500 nm
- Non-conductive and thermally insulating
- Stable < 900°C
- Improve coating quality by minimizing TE porosity

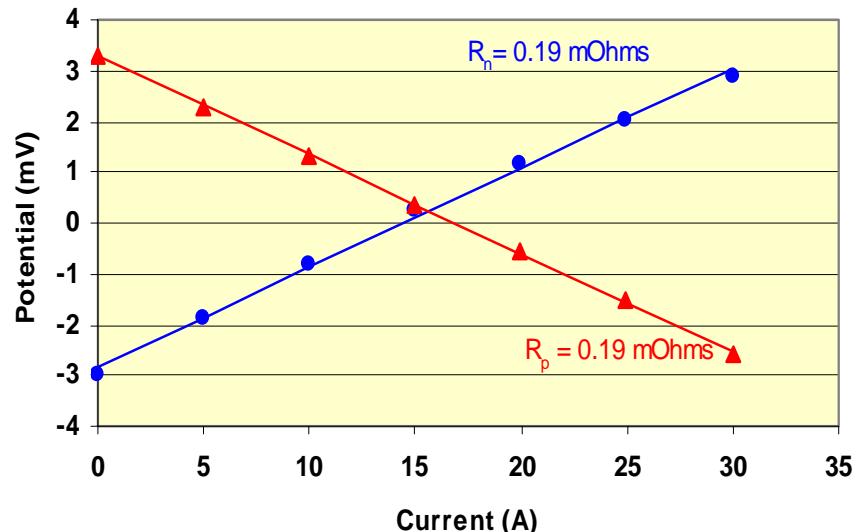
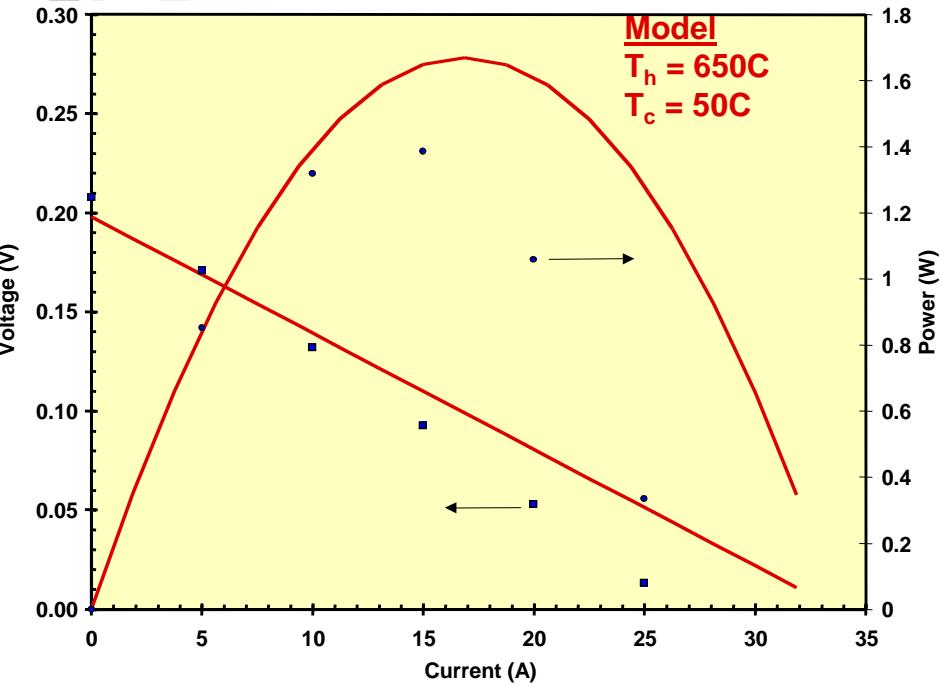
Sol-gel coatings suppress Sb sublimation



- Sample heated to 600C/dynamic vacuum/72 hours
- Single coat provides good protection

Unicouple testing





Contact resistance

- Primary objective: demonstrate 15% efficiency to match predicted performance
 - Consistently achieve > 10% efficiency
 - Hot-side, contact resistance must be reduced
 - Achieved by optimizing braze material and method of brazing



■ Thermal to Electric Power Generation

- Integration with any heat source
 - ◆ Combustors
 - ◆ Catalytic reactors
 - ◆ Radioisotope heat source

■ Waste heat recovery

- Automobile exhaust
 - ◆ Supplement or replace electrical power generator with electrical power generated from engine waste heat
 - ◆ $T \sim 600$ to 700C available at the catalytic converter
 - ◆ $\sim 1 \text{ kW}$ power generator
 - ◆ Cost is critical
- Power plants
- Geothermal energy
- Jet engines

■ Solid State Advantage

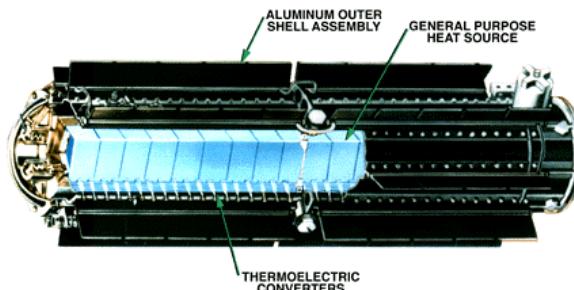
- No moving parts
- No maintenance
- Long life



Advanced Power Generation TE Modules

General Purpose Heat Source (GPHS)

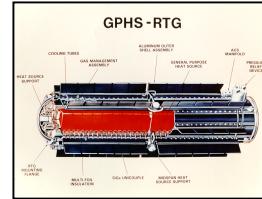
Radioisotope Thermoelectric Generator (RTG)



- POWER OUTPUT – 285 W(e)
- FUEL LOADING – 4400 W(t); 132,500 Ci
- WEIGHT – 124 lbs
- SIZE – 16.6 in x 44.5 in

The three Radioisotope Thermoelectric Generators (RTGs) provide electrical power for Cassini's instruments and computers. They are being provided by the U.S. Department of Energy.

Advanced TE Segmented Unicouples



Radioisotope Thermoelectric Generators

Waste heat Automobile



- **New segmented thermoelectric unicouples under development**

- Operating between 300 and ~ 1000K
 - Predicted efficiency up to 15 %

- **Unicouple fabrication and testing**

- Several segmented and non-segmented unicouples built for thermal and electrical testing
 - 10% thermal to electrical efficiency routinely demonstrated
 - Several engineering and processing challenges remain

Acknowledgement

- **NASA, DARPA and ONR**